PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Giancarlo D'Ago

Cycle: XXXVII

Training and Research Activities Report

Year: First

Giancarlo D'Ago

Tutor: Prof. Fabio Ruggiero

Fabio Ruggiero

Co-Tutor: Dr. Eng. Luca Rosario Buonocore
Prof. Vincenzo Lippiello

Date: December 13, 2022

1. Information:

- **PhD student:** Giancarlo D'Ago
- **DR number:** DR996238
- **Date of birth:** 13/09/1997
- **Master Science degree:** Automation Engineering - **University** of Naples 'Federico II'
- **Doctoral Cycle:** XXXVII
- **Scholarship type:** CERN Doctoral Student Programme
- **Tutor:** Prof. Fabio Ruggiero
- **Co-tutor:** Dr. Eng. Luca Rosario Buonocore, Prof. Vincenzo Lippiello

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Evento Enel	Seminar	1	0.2	01/02/2022	DIETI	Y
Study of implementation and simulation for the control of aerial manipulators. Revising paper *Modelling and control of a variable-length flexible beam on inspection ground robot* for ICRA22	Research		9.8	From 01/01/2022 to 28/02/2022		
Matrix Analysis for Signal Processing with MATLAB Examples	Course	8	2.0	22-23/03/22 5-7/04/22	DIETI	Y
Global and cluster synchronization in complex networks and beyond	Seminar	1	0.2	10/03/2022	DIETI	Y
IEEE Authorship and Open Access Symposium: Tips and Best Practices to Get Published from IEEE	Seminar	1.5	0.3	30/03/2022	IEEE	Y
Safety mask course	Seminar	1	0.2	06/04/2022	CERN	Y
MATLAB & Simulink Italian Academic Forum	Seminar	4	0.8	07/04/2022	MATLAB	Y
Service and companion robots in healthcare	Seminar	1.5	0.3	21/04/2022	DIETI	Y
On using simple optimization techniques for tuning of UAVs	Seminar	2	0.4	27/04/2022	DIETI	Y
Using Delays for Control	Seminar	2	0.4	21/04 - 28/04/2022	DIETI	Y
Study on: modelling and control of a dual-arm suspended flying robotic system with simulations in MATLAB and Gazebo. Low-level control of robotic arms, study on Can and CanOpen protocols. Laboratory activity: configuration and control of	Research		5.4	From 01/03/2022 to 30/04/2022		

electric brushless motors						
Statistical data analysis for science and engineering research	Course	12	4	22-24-29-31/03/22 5-7/04/22	DIETI	Y
Scientific Writing	Course	12	3.0	From 03/05/2022 to 23/05/2022	CERN	Y
IEEE 2022 ICRA WORKSHOP - Shared Autonomy in Physical Human-Robot Interaction: Adaptability and Trust	Seminar	8	1.6	23/05/2022	IEEE 2022 ICRA	Y
Vine robots: design challenges and unique opportunities	Seminar	1	0.2	31/05/2022	DIETI	Y
Study on: Modelling of a dual arm suspended flying robot. Creation of an optimization framework for the identification of dynamic parameters of a dual arm suspended flying robot. Analysis of experimental data from the real system. Laboratory activity: Configuration and control of electric brushless motors	Research		1.2	From 01/05/2022 to 30/06/2022		
General and Professional French Course	Course	80	6.0	April – July 2022	CERN	Y
Study on: refinement of the optimisation framework for identifying the dynamic parameters of a cable-suspended system. Experimental data analysis of an aerial cable-suspended system. Analysis of experimental data of a cable-suspended system suspended from an overhead crane. Modelling and simulation of cable-suspended systems. Preparation of the conference paper *Modelling, identification, and simulation of a cable-suspended dual-arm aerial manipulator*	Research		4.0	From 01/07/2022 to 31/08/2022		
9TH BE-CEM Students' Coffee	Seminars	1	0.2	12/10/2022	CERN	Y
Study on: improvements on the model-based oscillation suppression control for cable-suspended robotic systems. Model-free oscillation suppression for cable-suspended robots.	Research		9.8	From 01/09/2022 to 31/10/2022		

Study, simulation, and implementation on a dual-arm system. Preparation and submission of the conference paper *Modelling and identification methods for simulation of cable-suspended dual-arm robotic systems* for IEEE ICRA 23. Laboratory activity: documentation for the purchase of a motion capture optical systems for robotic activities. Configuration of electric drives for mobile robotic platforms. Collaboration on the re-implementation of low-level communication libraries with CANOpen protocol for robotic manipulators						
Operational Research: Mathematical Modelling, Methods, and Software Tools for Optimization Problems	Course	12	4.0	14-21-28/09, 05-12/10/2022	DIETI	Y
Crane Operator and Slinger	Course	16	0.0	22/11/2022 - 23/11/2022	CERN	Y
Fast Forward, the productivity system for researchers	Course	12	3.0	From 17/10/2022 to 2/12/2022	CERN	Y
Stabilizer Renyi Entropy and Quantum Complexity	Seminar	1	0.2	02/11/2022	DIETI	Y
Study on: oscillation suppression control of cable-suspended dual-arm robotic platforms. Model-free and model-based techniques. Control of underactuated systems: state-of-art research regarding energy control, passivity control, under actuation. Laboratory activity: Market research for Motion Capture sensor for Robotic System. Configuration of electric drives for mobile robotic platform. Collaboration on the re-implementation of low-level communication libraries with CANOpen protocol for robotic manipulators. First experiments on the real system. QR code detection for preliminary experiments	Research		2.8	From 01/11/2022 to 31/12/2022		

on the implementation of the model-free control technique for oscillation suppression. Collaboration with University of Seville in the AERIAL-CORE European Project. First implementation of the model-free control on the real system. Simulation in C++, ROS, Gazebo of the model-based control.						

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	**0.0**	**0.2**	**9.8**	**0.0**	**10.0**
Bimonth 2	**7.0**	**1.8**	**1.2**	**0.0**	**10.0**
Bimonth 3	**2.0**	**2.6**	**5.4**	**0.0**	**10.0**
Bimonth 4	**6.0**	**0.0**	**4.0**	**0.0**	**10.0**
Bimonth 5	**0.0**	**0.2**	**9.8**	**0.0**	**10.0**
Bimonth 6	**7.0**	**0.2**	**2.8**	**0.0**	**10.0**
Total	**22.0**	**5.0**	**33.0**	**0.0**	**60.0**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 - 4.8**	

3. Research activity:

Long-reach robotic manipulation aims to perform inspection and maintenance tasks in difficult-to-access workspaces. A recent challenge in this field is the execution of operations in high-altitude areas (e.g., maintenance of power lines, inspection of infrastructures, etc.) where the direct access of humans is dangerous or costly. It is clear that, in this context, the use of conventional serial or parallel robots is impractical due to their limited workspace, and alternative robot designs must be leveraged. In these scenarios, manipulators in a long-reach pendulum configuration are usually employed. They are constructed using one or multiple cables that: (i) dramatically decrease the weight of the overall robotic system compared to using rigid links only; (ii) provide orders of magnitude larger end-effector workspace without affecting the weight of the manipulators' base; and (iii) exhibit superior resilience to absorb external disturbances such as impacts and collisions. Despite the clear advantages of using cable-suspended long-reach manipulators, they are generally more difficult to control due to the presence of non-actuated and flexible elements (cables) that make the entire system prone to uncontrolled oscillation.

The conducted research aims to model, identify, simulate, and control this type. The study carried out during this first year involved the search for a model that could capture the dynamic effect of a suspended articulated system as the ones considered. For the study of the dynamics, the behaviour of

two case studies has been analysed: the first system is a bi-manual system designed by the BE-CEM-MRO section at the European Organization for Nuclear Research (CERN) for the inspection and maintenance of particle accelerator-related infrastructures. In this case, a set of pulleys and steel ropes, coupled through a hook to a lower platform, serves as a lifting mechanism to hoist an articulated system (two Schunk LWA 4P arms) from an overhead crane. The second is an aerial cable-suspended dual-arm system developed by the GRVC Robotics Labs at the University of Seville used to install bird diverters on high-voltage power line. In that system, four belts, tied in a parallel pattern to a drone and to a lower platform, hold two four-DoF (Degree of Freedom) manipulators.

Long-reach cable-suspended articulated system modelling was carried out using the screw theory and Newton-Euler approaches. Since the real cable structure forms a closed kinematic chain, an equivalent open kinematic chain is adopted to simulate these systems using customary rigid-body dynamic simulators. The equivalence between the adopted open kinematic chain and the real system has been established by finding a set of dynamic parameters that maximize the similarity of their dynamic response. A set of experiments was conducted on both the systems case of study, and an identification procedure involving the solution of an optimization problem was developed. Once an estimate has been obtained, parameters are appropriately replaced into the model, and the behaviour of the simulated system is compared with a new set of experiments on the real platforms. This research work led to the production of a conference paper [P2] submitted in September 2022 to the 2023 IEEE International Conference on Robotics and Automation (ICRA), which is the result of a collaboration between CERN, PRISMA Lab of University of Naples 'Federico II' and GRVC Robotics Lab of University of Seville.

The control problem addressed during the first year is the suppression of the oscillation of the system during the transport of the dual-arm robotic system. As anticipated, despite the advantages of using cable-suspension, the system is prone to difficult-to-control oscillations, hence the objective of the control is to reduce the settling time of the oscillation. This first phase of the research addresses the actuation of the articulated system only to accomplish the suppression task. Two different control strategies have been studied. The first is a model-based control strategy, namely non-collocated partial feedback linearization, suitable for underactuated system, simulations through mathematics computation softwares (MATLAB), rigid-body dynamic simulators (Gazebo) and Operating Systems for Robotics (ROS) have been carried out. The second is a model-free energy-based control technique, which has been implemented and tested at the University of Seville. Both the strategies have shown promising results.

Parallel projects conducted during the year called for the configuration and control of electric motors (considering a possible replacement at CERN of the above-mentioned robotic arms with arms developed entirely by the section) and collaboration on the re-implementation of low-level code for position and speed control bug fixing and torque control enablement. A further paper produced during the master's thesis and concerning modeling and control of a variable-length flexible beam on inspection ground robot [P1], was published at the 2022 IEEE International Conference on Robotics and Automation (ICRA).

During the coming year, the dynamic model of the system will be improved and extended, and new identifications will be made to ensure a complete adherence of the simulation to the real model. The theoretical foundations of the control will then be investigated for performance evaluation and further improvements and modifications. The control laws will be tested on both case studies in different

application cases. It is envisaged that the work will lead to the production and submission of one or more scientific articles to internationally renowned journals.

4. Research products:

[P1]
Scientific paper: Modelling and control of a variable-length flexible beam on inspection ground robot
Authors: G. D'Ago, M. Lefebvre, L. R. Buonocore, F. Ruggiero, M. Di Castro, V. Lippiello
Conference: IEEE International Conference on Robotics and Automation (ICRA), 2022
Year of publication: 2022
Current state: published.

[P2]
Scientific paper: Modelling and identification methods for simulation of cable-suspended dual-arm robotic systems
Authors: G. D'Ago, M. Selvaggio, A. Suarez, F. J. Ganán Onieva, L. R. Buonocore, V. Lippiello, A. Ollero, F. Ruggiero
Conference: IEEE International Conference on Robotics and Automation (ICRA), 2023
Current state: submitted.

5. Conferences and seminars attended

6. Activity abroad:

7. Tutorship